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UNIQUE APPROACHES TO BMDO/ISTEF OPTICAL SYSTEMS DESIGN

by

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Abstract

Recently, two 12.5-inch diameter aperture Small Transportable ISTEF Pedestal System (STRIPS) telescopes were designed using all-reflective optics in order to provide four optical bands ranging from 0.3-microns to 15.0-microns on a single instrument mount. Each telescope provides three focal panes/focal lengths for a maximum 1-inch diameter circular image plane. As the name implies, these telescopes are easily transportable (by air, land and sea), and capable of being installed in a temporaray and primitive field site within a short period of time...without having to spend hours in optical alignment. This paper describes in detail the individual steps taken to design, fabricate and assemble two complete telescopes, and six secondary system modules in less than six months and within a total budget of under $150K. The methodology employed serves as a highly cost-effective model for future optical range instrumentation.

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Presentation Outline

- background information
- technical requirements
- optical design considerations
- mechanical design considerations
- summary & acknowledgments

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Background Information

The Ballistic Missile Defense Organization's (BMDO) Innovative Science Technology Facility (ISTEF) which is located at the Kennedy Space Center near Cocoa Beach, Florida, performs Optical Target Characterization (OTC) by applying state-of-the-art active and passive optical sources, sensors and techniques to develop and demonstrate innovative scientific concepts relating to BMDO missions. These missions include booster typing, tracking, target discrimination, aim point selection and kill assessment. The ISTEF supports research in a number of photonic technology areas including passive UV through LWIR imaging and tracking, active plume and hardbody signatures, laser radar and active imaging as well as sensor data fusion. The OTC Program supports these R&D specialties for missile defense. In summary, the ISTEF is a dedicated electro-optical facility for conducting research, development, test and evaluation on new sensor technologies and algorithms in the area of missile defense. It is Government owned and managed, and is operated by on-site contractors.

Background Information

Over the past several years BMDO has required and encouraged innovation in scientific and technical (S&T) instrumentation in order to meet ever more demanding R&D data collection requirements in both active and passive electro-optical systems. These needs have been met and are rapidly augmenting existing mobile optical tracking capabilities worldwide. During a number of ISTEF deployments these past 3 years, it has been noted that the ISTEF-sponsored equipment and collection methodologies, including software controls, algorithms and analysis tools, have been used by associated organizations and government agencies to enhance the value of "independent or stand-alone" range instrumentation.

Optical range instrumentation must in general, operate in harsh environments ranging from temperature extremes of 160 degrees F. to oftentimes, below freezing. These same environmental constraints represent the challenges faced by the ISTEF and its supporting contractors and pose additional environmental concerns on the design of BMDO-sponsored optical telescopes. These constraints include operating in a very humid, salt-ladened atmosphere. Telescopes deployed at the Cape must be available 24 hours a day both for night launches under sometimes cold, damp and foggy conditions and for day launches under hot, humid and occasionally cloudy, conditions.

There are also many other factors which affect telescope design for instruments used at the Cape (Kennedy Space Center, FL). These factors include the dynamics of tracking rocket launches with the attendant problems of pointing, maintaining optical alignment, and reducing the deleterious effects of mount vibration and stresses from operating the telescope mount at high slewing rates. Since mounts at the ISTEF usually support more than one telescope per mission, an optimum design must address the problem of co-aligning multiple telescopes with each other and maintaining this configuration throughout the mission. In summary, optical range instrumentation at the Cape has to meet a variety of stringent requirements usually under less than optimum environmental and operational conditions.

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Technical Requirements

- multiple focal lengths
- interchangeable modules
- UV to LWIR in 4 bands
- thermally stable
- robust design
- easily transportable

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Technical Requirements

The first requirement was for a module which held a spider mount and secondary mirror system and provided a base line 150-inch effective focal length (efl). The second requirement was for a 300-inch efl module to perform long range target tracking. The final requirement was for an afocal module designed to accommodate a wide range of unique detector focal plane configurations including any future advanced capability focal planes currently under development.

In addition to the need for modularity, other general technical requirements included a method of rapidly changing fixed focal lengths, a way to share a common aperture and cover 4 optical bands, a mechanical means for maintaining a stable focal plane over a temperature range of 160 degrees and a structure design to withstand hostile operating environments.

As the name STRIPS implies, these telescopes had to be easy to transport (by air, land and sea) and capable of being installed in a temporary and primitive field site within a short period of time....without having to spend hours in optical alignment. The modular approach taken in this case allowed the SPAWAR machine shop in San Diego, CA, and the Space Optics Research Lab optical fabrication facility in Chelmsford, MA, a degree of flexibility in matching materials and mounting the various optical components.

Optical Design Considerations

Owing to the STRIPS requirement to cover multiple wavelengths over the optical spectral region from the ultraviolet through the long-wavelength infrared, an all-reflecting, two-mirror base line telescope design approach was taken. Special attention was given to the following four bands: the ultraviolet from 0.3 to 0.4-microns (UV), the visible and near-infrared from 0.4 to 1.8-microns (VIZ/NIR), the middle-wavelength infrared from 2.3 to 5.5-microns (MWIR), and the long-wavelength infrared from 8.0 to 15.0-microns (LWIR).

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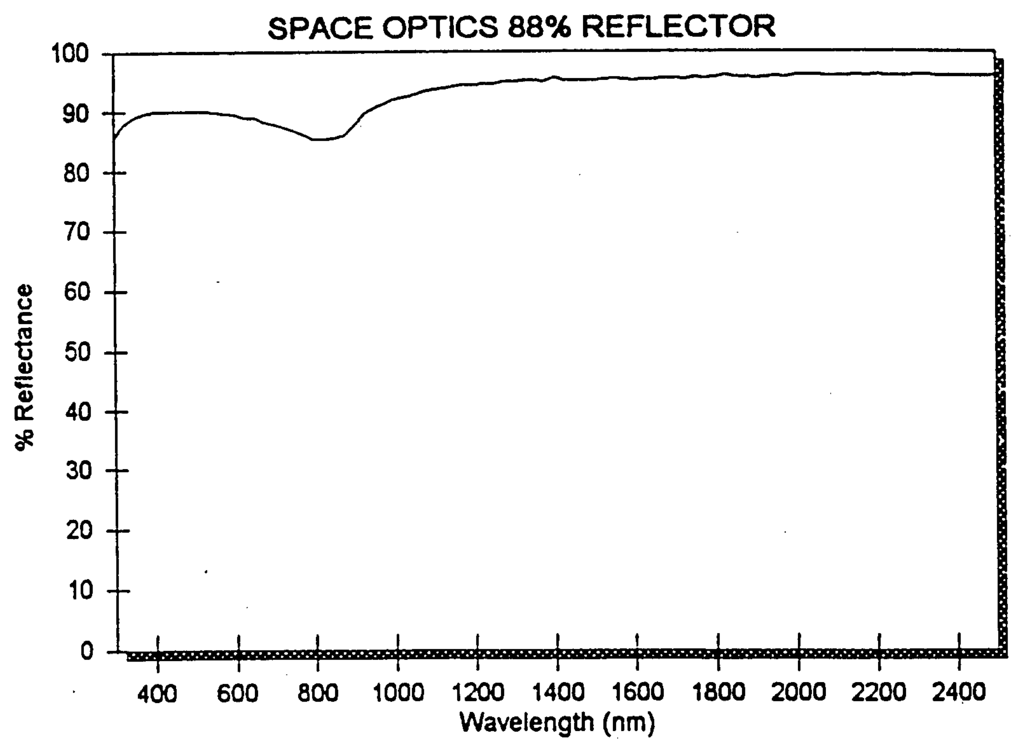

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In terms of optimizing the transmission or "throughput" of the STRIPS instrument, all mirrors were coated with a Pilkington front surface aluminum mirror No. 747 coating. The No. 747 coating is a very broadband, optically reflecting coating which provides optimum reflection in the UV (about 75% at 0.3-microns and 88% at 0.4-microns) while performing well at all other wavelengths, up to 98% at 15.0-microns. Given the adverse climatic conditions at the ISTEF, pinholes in the coating had to be eliminated.

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Modular Configuration

- 150-inch EFL = base line design
- 300-inch EFL = 2X base line design
- Afocal design = special focal planes

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Optical Design Trade-Offs

The STRIPS design also had to accommodate an afocal configuration of two mirrors with relay lenses and dichroic beamsplitters. The need to build two identical telescopes arose from a desire to produce four bands of imagery simultaneously with a common image scale factor.

During the initial period of reviewing optical design trade-offs, it was noted that an EFL of between 130 and 150-inches would require a Ritchey-Chretien configuration and that this more sophisticated design would add to the cost and schedule of the base line telescope. Therefore, a classical 150-inch EFL Cassegrainian configuration with a focal plane diameter of 1.0-inch was selected as the most cost-effective approach.

This choice of focal length meant that a 12.5-inch diameter primary mirror and a 4.5-inch diameter secondary mirror could be manufactured in a minimum of time using standard test tooling and optical shop practices. Secondary mirrors could be final-figured in autocollimation against each parent or the best of two primary mirrors.

Two additional focal lengths, i.e., 300-inch and afocal, were selected for the following reasons: (1) to "double" the base line design of 150-inches, and (2) to add a capability for evaluating future focal plane arrays and matching image format to specific operational missions. These additional "focal lengths" created the need for modular telescope construction. It also required a general method for "athermalizing" the optical train.

Optical Design Considerations

Co-Alignment, Baffling and Optical Cross-Section Approaches

In operation, the two STRIPS telescopes are arranged side-by-side (or over-under) on a tracking mount (pedestal) and must be co-aligned prior to observing a rocket launch. This task is accomplished easily with an elevation over azimuth (EL-AZ) adapter which connects the basic telescope to its pedestal.

Adjustments up to ± 3 degrees is possible with these adapters. A high degree of leverage has been designed into the elevation axis which allows an operator to exercise precise control of the pointing direction regardless of the weight of the telescope, module and channel beam support assembly.

Stray light degrades image contrast especially, during daylight tracking operations and near the solar disk. Stray light (veiling glare) is always a concern for optical instrumentation on the range. In the case of infrared detectors, thermal radiation is also a concern. Therefore, baffles and stops for the STRIPS telescopes were designed to handle both concerns. In the UV through the visible portion of the optical spectrum, baffles had to be optimized for all three telescope configurations. In fact, the STRIPS telescopes incorporate a baffle with each module. Each baffle is attached to its secondary mirror cell. These cells are attached to their secondary spider mounts through an alignment mechanism.

All the hardware is either of low optical cross-section design or concealed in the "shadow" of the secondary mirror cell. All surfaces are blackened to reduce reflections within the telescope housing. Care has been exercised to reduce the optical cross-section of all internal hardware to a minimum in order to prevent unwanted optical radiation from reaching the telescope's primary focal plane. Furthermore, provisions have been made to place stops at the ends of the baffles and within the hole in the primary mirror to avoid radiation which might "leak" into the detector region by way of ray bounce or warming of the mechanical parts.

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Mechanical Trade-Offs

- modularity
- rigid structure
- optical components

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Mechanical Design Considerations

Implicit in this method of modularity was the requirement for ease in field assembly and highly repeatable interfaces. Therefore, a kinematic approach was used to attach each module to its basic telescope "headring". Each basic telescope headring design used a traditional kinematic, i.e., flat-cone-groove, load bearing surface. The same rods which were used for longitudinal support of the telescope components and cells were threaded and used to capture each set of mating headrings. A 77-inch long channel beam was placed under the basic telescope to insure rigidity of the entire assembly. This basic telescope backplate was attached to this channel beam with a "shoe assembly" in order to facilitate field alignment and further strengthen the telescope assembly.

Three Invar spacer rods were extended beyond the basic telescope headring to act as a positive location for each of the secondary mirrors. These rods also serve as guiderails for the module assembly phase. In this way, the inter-mirror distance is guaranteed to remain constant throughout a wide variation in ambient temperatures (approximately 160 degrees F.).

In order to properly support the high quality optical components, all mirrors were manufactured to fit fully into cells using RTV 31 for edge and back support. A well-established procedure which insures uniform support of the optics at all elevation angles and under a variety of stressful operating conditions was used for potting all eight mirrors. The larger mirrors were "grooved" to insure positive location along the optical Z- axis. The smaller mirrors were mounted in a full lap of RTV 31 and restrained in Z-axis by the bonding contact. Retainer rings were used only to insure backup safety of the mirrors and provide an aperture stop for light rays entering the telescope.

Mechanical Design Considerations

Consideration for the assembly of all the optical components included a scheme to insure "optical quality" alignment of the baffles especially, since the baffles become an optical aperture in a now well-defined lens system. In the case of the primary mirror, the primary mirror baffle was attached to a cylindrical adapter which connects the primary mirror cell to the telescope back plate (back of the telescope). The primary mirror which had been previously loaded into its cell, was brought into alignment with the baffle by three adjustment screws located in the mirror cell. These screws then supported the primary mirror temporarily while RTV 31 was being poured into the mold which was formed around the mirror edge. After curing, the cell, mirror and baffle were brought into mechanical alignment with the basic telescope.

In the case of the secondary mirrors, each optical component was aligned with its baffle in an individual (customized) secondary housing assembly and was set at a nominal distance from the module's head ring. The nominal distance in this case was the intermirror distance minus the distance from the primary mirror vertex to the face of the basic telescope head ring. This calculated distance places the secondary mirror surface near an exact distance which can produce a perfect image at the appropriate back focus. This total intermirror distance then, is adjusted only once and from this point on, relies on mating the kinematically designed head rings. Obviously, the kinematic contact points must remain free of foreign particles during the attachment operation.

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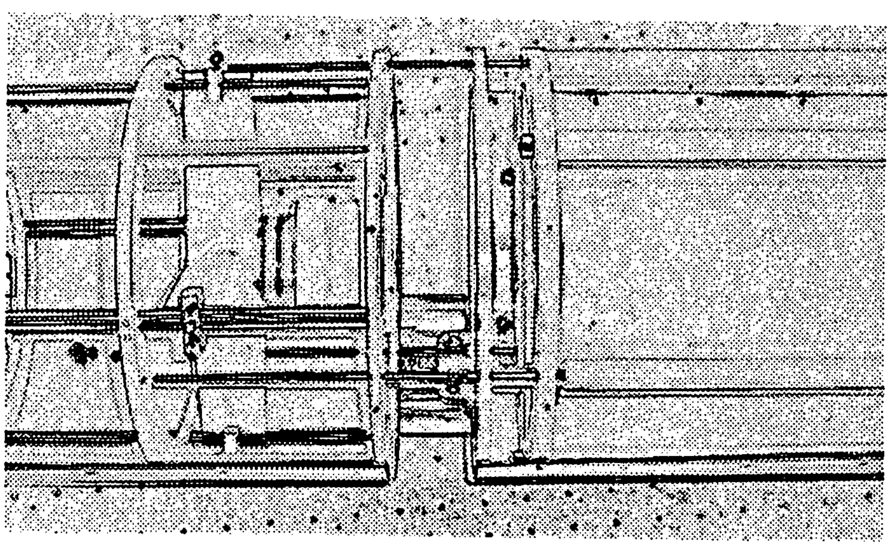

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Mechanical Design Considerations

At this point in the alignment procedure, tip and tilt adjustments of the secondary cell are used to bring the optical axis into nominal alignment with the module's mechanical axis. Following this operation, the module is attached kinematically to the basic telescope using the Invar rods and channel beam support as a guiderail. Once the two headrings are positively connected, the optical centerline of the mirrors is brought into coincidence with the mechanical centerline of the entire assembly using small flats and reticles which have been fabricated onto the surface of the secondary mirrors. These "fiducials" together with adjustments on the secondary mirror cell adapter, allow each secondary mirror to be uniquely aligned with its primary mirror. The secondary mirror cell also utilizes a completely decoupled X-Y, tip-tilt and Z-axis design with the tip-tilt portion providing motion in elevation and azimuth, i.e., 90 degrees (instead of 120 degrees which is used commonly in 3-point cell support designs). This decoupling of the degrees of freedom and the use of fine-motion screws enables simple optical alignment. This ability to rapidly align the system is important for the optical shop following refurbishment of the optical components or, if necessary, as part of a field checkout procedure conducted between extended periods of launch operations.

During the final alignment phase of the STRIPS telescope assembly operation, a low power He-Ne laser was used behind the backplate and near the focal plane of the telescope, to establish a highly visible optical centerline and finally, as the light source for a laser unequal path interferometer (LUPI). This application provides for quantifying the optical wavefront both with the initial (original) alignment and for validating the repeatability of the kinematic interface. Full wave-front interferograms of two repetitions are shown below. Note that there was no change in wavefront quality from disassembly to reassembly.

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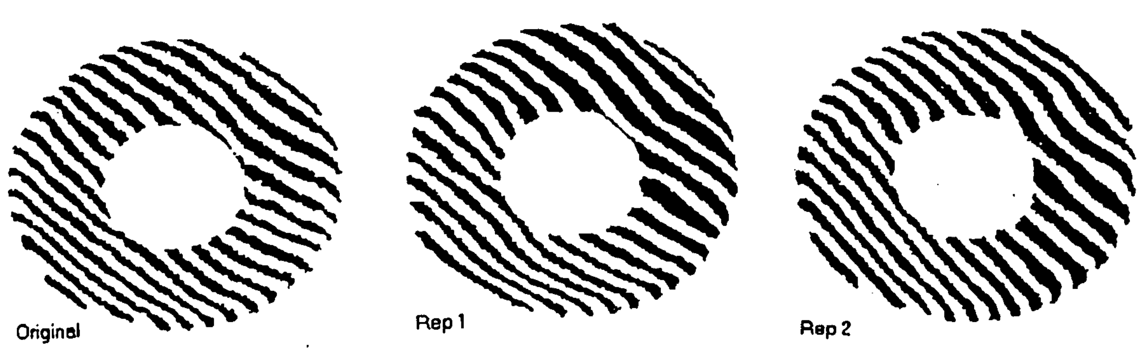

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Mechanical Design Considerations

Thermal Path, Structural Integrity and Deployment Approaches

Athermalization of the optical system was accomplished using Invar spacer rods. However, the means for attaching the aluminum metal primary mirror cell to aluminum ribs and eventually, to another aluminum mirror cell, represented no small challenge. In order to eliminate the effects of overall telescope housing expansion and contraction, a set of guide and transfer rings had to be installed between the aluminum ribs which in turn, had to support the telescope skin. Athermalization therefore, was accomplished by using three Invar rods separated by 120 degrees around the telescope axis, alternating with three aluminum rods located 60 degrees around the circle from its Invar counterpart. Altogether, six rods are used to create the telescope "tube" appearance. The Invar rods are allowed to "clear" the aluminum rings/ribs. These rods attach only to the aluminum primary mirror cell and to each module's transfer ring.

The aluminum rods, on the other hand, are used to support the head rings and telescope skin. The skin is allowed to clear the critical head rings by a few thousandths of an inch thus allowing the skin to expand and contract without regard to the attachment points of the critical components. Basically, the thermally sensitive aluminum path between the main telescope body and its associated module is isolated from the critical path of the optics. The critical thermal path then, is constructed entirely of Invar.

Finally, the channel support beam aids in maintaining mechanical integrity between the two parts of the telescope assembly, i.e., the basic telescope and the secondary module housings.

After fabricating the two basic telescopes, six secondary mirror modules, and two EL-AZ adapters with attached channel beam supports, a set of five, custom designed, instrument cases were constructed. These cases provide not only for the safe mounting of all the optical systems but also offer weather-resistant packing for transportation via surface, air or shipboard. Attention has been given to the concerns for ease of storage and rapid deployment into the field. A degree of shock protection has also been incorporated into the design.

Summary and Acknowledgments

Summary

STRIPS represents a simple approach to multi-wavelength, multi-focal length instrumentation for the range. It is easily transportable by air, land and sea and capable of being installed in a temporary and primitive field site within a short period of time. The modular approach taken in this case allows flexibility in planning for rocket launches at the Cape and for other technical data collection activities world-wide. This paper has described the individual steps which were taken to design, fabricate and assemble two complete telescopes, six secondary system modules, two precision EL-AZ mount adapters, and five instrument cases, in less than six months and within a total budget of under $150K. The methodology employed serves as a highly cost-effective and efficient model for future optical range instrumentation design and production activities.

Acknowledgments

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